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APPROACH FOR SERVICE LIFE EXTENSION OF EXPLOSIVE DEVICES FOR AIRCRAFT ESCAPE SYSTEMS

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SUMMARY

Service life extension of explosive devices used in aircraft escape systems can achieve considerable savings. An overall approach is needed to challenge the logic of explosive component service extension from design to removal from service for evaluation. The purpose of the effort described in this paper was to develop a service-extension approach on explosive devices used in aircraft systems, supported by actual testing of representative candidate devices, to evaluate quantitatively the effects of service, age, and degradation, and allow responsible, conservative service life determinations. Evaluated were five explosive components: rigid and flexible explosive transfer lines, one-way transfers, flexible linear shaped charges, and initiation handles. The service extension approach generated in this effort is summarized by eight recommendations.

INTRODUCTION

Extending the service life of explosive devices used in aircraft crew escape systems provides an opportunity for considerable savings for a variety of military and NASA aircraft. The rated service life of explosive devices for aircraft crew escape has been established on a necessarily conservative basis, with an equally cautious attitude toward service life extensions. Past service life surveillance programs have relied on test methods that have provided limited information to establish the functional status of devices having full service and to project further service extensions. The purpose of the effort described in this paper was to develop a service-extension approach on explosive devices used in aircraft escape systems, supported by actual testing of representative candidate devices, to evaluate quantitatively the effects of service, age and degradation, and allow responsible, conservative service life determinations.

A wide variety of explosive devices have been successfully applied to virtually all military aircraft to provide emergency escape for flight crews. For example on

the B-1B aircraft, initiation handles initiate both rigid and flexible explosive transfer lines (the interconnected network used to transfer an explosive stimulus to actuate all subsystems). One-way transfers isolate various portions of the network by allowing the transfer stimulus to pass in only one direction. Flexible linear shaped charges are used to sever the crew access ladder. Event sequencing is accomplished by in-line time delays, which are slow-burning fuse elements. Mode selectors allow the command pilot to select the ejection sequence of the four escape seats. "And" gates assure that one escape event has occurred prior to another. Thrusters are used to jettison overhead canopies to allow clear passage for the ejection seats.

The establishment of the rated service life for military aircraft explosive devices has been approached on a conservative basis because of the human-life-critical function they perform. The concept that all explosives are unstable was mistakenly extrapolated to the materials used in these devices, and consequently, a relatively short service life was arbitrarily established. Since service evaluation is normally accomplished by organizations that are separate from the design group, a design for long service is generally not emphasized. Furthermore, little technology exchange on service life has occurred among the various aircraft programs; as of 1981 the rated service life of rigid explosive transfer lines (ref. 1) typically ranged from 3 years on the B-1 to 15 years on the F-16, with the rated service of most aircraft systems established at 5 years for essentially the same transfer line materials and design.

Extending service not only provides cost savings, but can improve system reliability. Removal and replacement (changeout) costs include removal of the aircraft from service, transfer of the aircraft to and from refurbishment sites, procurement of replacement components and a specially trained labor force. Changeout often requires removing large sections of the airplane. For example, approximately 600 manhours are required to remove the nose section of the F-14 and to replace approximately 150 explosive transfer lines. Approximately 40 000 manhours were

required to de-mate the B-1 crew module and to replace the escape system, which included 1200 transfer lines. System reliability can be improved by avoiding too frequent teardown and replacement of explosive devices, with the accompanying potential of damage and improper assembly.

To benefit from an explosive device service extension, a number of surveillance programs are being conducted. No acceptable method, such as elevated-temperature "accelerated aging" (ref. 2), has been developed and substantiated to predict reliably service life limits for explosive devices. The approach used by past surveillance programs was to remove and replace devices on completion of rated service. The removed devices were examined visually and by X-ray and subjected to a repeat of all, or a portion of, the initial lot acceptance and qualification testing. The devices were then functionally tested, (fired). Prior to the effort described in reference 1, functional testing was primarily on a "go/no-go" basis. That is, the device did or did not function.

"Go/no-go" testing provides little information on the actual status of explosive devices. If the device functioned, how well did it perform, or was there any change? Can service life be extended, and if so, for how long? If the device failed to function, how, where within the device, and when did it fail? Was the failure caused by a previously undetected design weakness, by improper installation, by service, or by the removal process?

To answer these questions and allow service extension of explosive devices, an entirely different philosophy than "go/no-go" is needed, starting with system conception: (1) components should be designed for long-term use, (2) nondestructive inspection methods are needed to assure component readiness, (3) functional performance and chemical analysis methods are needed that are sensitive to small changes, (4) a test approach is needed to gain confidence in service extension, and (5) a method is needed to determine component failure mechanisms.

This paper describes the extension approach applied to five different explosive components with test results and recommendations.

TEST ITEMS

This section provides a generalized physical description with advantages and disadvantages for long-term service for five explosive devices: rigid explosive transfer lines, flexible explosive transfer lines, one-way transfers, flexible linear shaped charge, and initiation handles.

Rigid Explosive Transfer Lines

Rigid explosive transfer lines, shown in figure 1, are completely sealed assemblies within stainless steel. Both ends (one shown in fig. 1) are identical. Highly stable explosive materials are used throughout; the tips contain hexanitrostilbene (HNS-I), with hexanitrobibenzy (HNBiB) and the mild detonating cord contains either HNS-II (recrystalized HNS-I) or dipicramide (DIPAM). The cord sheath materials are either silver or aluminum. The cord is fully supported within the steel tube. The only disadvantage is that the thin walls (0.005 inch) of the booster tip require careful handling during installation to prevent damage.

Flexible Explosive Transfer Lines

Flexible explosive transfer lines, shown in figure 2, are mechanically sealed assemblies (crimped and potted). Flexible lines accomplish the same function as rigid lines. The mild detonating cord contains HNS-II with a lead (Army application) or aluminum (Air Force application) sheath. The cord is overlaid with polyethylene tubing and fiberglass, which produces a relatively rugged structure. Disadvantages are that the explosive materials are not hermetically sealed, the cords are subject to undetectable damage by impact, crimping or flexing, and the thin-walled tips must be handled carefully.

One-Way Transfers

One-way transfers use HNS-I explosive materials that are contained in stainless steel cavities as shown in figure 3. The cavities are hermetically sealed with a stainless steel foil. There are no disadvantages in this design to prevent long-term service.

Flexible Linear Shaped Charge

The flexible linear shaped charges evaluated in this program contained HNS-II, and the sheath material was aluminum for the B-1, figure 4, and lead for the AH-1S. The ends have thin-walled booster tips that are potted. The installation is fully supported down the length of the charge to prevent environmentally induced damage. However, the potted assemblies are not hermetically sealed.

Initiation Handles

A typical initiation handle, which is used to initiate rigid or flexible explosive transfer lines, is shown in figure 5. This handle requires a 90° twist and pull to compress the firing pin's spring. When the sear is pulled out of the body, the firing pin is released and driven by the spring into the percussion primer. The primer initiates lead azide, which detonates HNS-I in the output tip. The mechanical interfaces are designed for long service, but the percussion primer is the weakest link in the system. Primers are not sealed and are sensitive to moisture and impurities, installation, age, temperature and mechanical environments.

PROCEDURE

Similar test methods and experimental approaches were applied to all devices.

Test Methods

The devices were evaluated functionally and chemically as detailed in references 1, 3, and 4. Velocity measurements were made of detonation fronts within explosive columns and of explosively driven fragments at the output of devices, using

"make" switches and electronic timing circuits. The output energy of several devices was measured, using a piston/cylinder, crushing honeycomb apparatus. The status of the explosive materials in the devices was determined using high pressure liquid chromatography (HPLC), which provides the quantity of each explosive by weight in a sample, color photographs, and scanning electron microscopy. Samples from each test group were dissected at several points for analysis.

Flex and wrap tests were conducted on flexible explosive transfer lines. An Army AH-1G application allowed crew members to use the lines as handholds. Service conditions were simulated by hand pulls, followed by vibration. The Air Force specification required the lines to be wrapped around a 4-inch diameter cylinder. A total of 2000 wrap cycles were conducted on an electrical motor-powered cylinder with an axial load of 20 to 40 pounds on the line. The lines were held by elastic cords, causing the load to increase as the cylinder rotated.

The cutting ability of the flexible linear shaped charge was determined, using tapered 2024-T4 aluminum witness plates. The plates were 2 × 12 inches, tapering down the length from 0.020 to 0.200 inch. Two simultaneous cuts were made on each plate.

Experimental Approach

The explosive devices evaluated in this effort had both no service and full rated service, being removed from active aircraft.

Nondestructive tests included visual examination and X-ray with helium leak tests for sample groups of the rigid explosive transfer line end tips. Visual examination and X-ray inspections were applied on receipt and after each environmental test.

The "performance standard" groups were used to establish functional performance and chemical composition standards against which all subsequent test groups were

compared. The most recently manufactured devices with the least service, preferably new, were used.

Service life demonstration groups measured functional performance and chemical composition following full rated service.

Repeat thermal qualification tests were conducted on several devices, following full rated service to gain confidence in service extension. Mechanical environmental tests were not conducted, since past experience had shown that the devices were unaffected by qualification-level mechanical inputs.

Degradation investigations were conducted on a number of devices to determine what chemical and physical changes take place as devices degrade, and how much degradation causes functional failure. The only known method for inducing degradation was through exposure to elevated temperatures, since no age affect had been proven.

The actual tests conducted on each device are detailed in the tables of results.

RESULTS AND DISCUSSION

The results of each explosive device will be presented individually. In general, the inspection, functional and chemical monitoring methods were able to detect small changes.

Rigid Explosive Transfer Lines

Evaluated in reference 1 were lines removed from the Army's AH-1G and AH-1S, the Air Force's F-111 and B-1A, and the Navy's F-14. Table I for the AH-1S aircraft is typical. All line types have excellent performance reproducibility. No detectable change was observed, due to age or service, or full service with a repeat thermal qualification. There is no apparent service limit. Degradation occurred only under thermal conditions that were well above service requirements.

Flexible Explosive Transfer Lines

The explosive materials in the B-1 line's mild detonating cord were significantly degraded by 450°F annealing cycles (Table II) applied prior to manufacturing of the cord to maintain necessary flexibility.* Both the B-1 aluminum-sheathed cord and the Army's lead-sheathed cord have excellent performance reproducibility. Potted tips (Army version) with no mechanical support loosened with service. The explosive materials were unaffected by age, service, or full service with a repeat thermal qualification. Chemical analyses revealed that the stability of the explosive in the tips was superior to those in the rigid lines, since the tips vented. Hermetically sealed tips, such as those on rigid transfer lines, prevent venting of decomposition gases, accelerating decomposition.

The army's "handhold" problem induced 9 cords to part (and resultant failures-to-function) in a sample of 120 units. These failures were simulated in laboratory tests with hand pulls, followed by vibration exposure. Neither individual environment alone caused the cord to part.

The Air Force's wrap tests caused 4 of 11 units to fracture the cord; two functioned normally. Three units that had been sharply kinked, prior to testing, suffered cord fractures in less than 1000 cycles. It was learned that the original qualification tests were conducted by hand-wrapping with no axial load.

One-Way Transfers

The functional performance exhibited appreciable variations, as shown in Table III, but meets specification requirements. No detectable change was observed, due to age or service to 3 years, or full service with a repeat thermal qualification. There is no apparent service limit.

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*The degradation induced by annealing was indicated by the low quantity of explosive (92.3%) in the service life demonstration test group, and confirmed by color photography showing a darker than normal appearance. Furthermore, no group of B-1 rigid transfer lines, containing the same material, exhibited such low quantities of explosive.

Flexible Linear Shaped Charge

The results of the B-1A flexible linear shaped charge are shown in Table IV. Both types tested had excellent performance reproducibility. Potted tips with no mechanical support (B-1A) loosened with service. The explosive materials were unaffected by age, service, or full service with a repeat thermal qualification. Chemical analyses revealed that the explosive stability was superior to rigid lines, since the end tips vented.

Initiation Handles

Demonstration tests were run on AH-1G arming/firing mechanisms after 5 years of service. The firing mechanisms performed normally. The output tips produced sufficient energy to initiate a booster tip for a rigid or flexible transfer line. However, no attempt was made to evaluate the change in initiation sensitivity or output performance of the percussion primer, (the element that would most likely degrade). This evaluation would necessitate removal of the primers from the device, which would be extremely difficult without damaging the primers. Furthermore, a thorough evaluation could require hundreds of primers, due to the necessary statistical approach. No attempt was made to chemically evaluate the explosive materials, due to the hazards of handling the lead azide in the booster column.

RECOMMENDATIONS

The recommendations from this program can be individually enumerated:

1. This test methodology (inspection, chemical, and functional) should be incorporated into original specifications for lot acceptance, then used for subsequent evaluation testing.
2. "Accelerated aging" should not be applied, since there is no verified relationship to age or service. Furthermore, this type of test can eliminate completely satisfactory components because of unrealistic high-temperature

exposures. Real-time exposures to actual high-temperature conditions is acceptable.

3. The approach for service extension should be:
   (a) Compare the requirements of the system with the state-of-the-art service demonstrated by other systems.
   (b) If the device has promising design features (stable explosives, seals, insensitivity to environments, etc.), leave installed for rated service, then evaluate a sample of the population from worst-case environments, using the methodology described in item 1.
4. Rigid explosive transfer lines should be considered for service extension for all applications.
5. Flexible explosive transfer lines should allow only thermal annealing cycles that do not exceed 350°F. Since potting cannot maintain absolute seals with service and units can suffer undetectable damage: tips should be mechanically supported, the flexible lengths should be well supported, and protection from abuse should be provided. Service life extension should be cautious. To allow continuation, assure that the service environment does not vary appreciably from the previously demonstrated service conditions.
6. One-way transfers should be considered for service life extension for all applications.
7. Flexible linear shaped charge applications should provide mechanical supports of end tips to maintain seals and performance. Service extension should be cautious. To allow continuation, assure that the service environment does not vary appreciably from the previously demonstrated service conditions.
8. For initiation handles, percussion primers are the weakest component. Service extension should be approached with extreme caution, due to the difficulty in fully evaluating all explosive components, particularly the percussion primer. A national need exists to incorporate an improved

percussion primer before serious service extension can be considered. A study is needed to subject a large sample of "improved primers" to real-time aging under simulated-environment flight conditions.

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TABLE I. - FUNCTIONAL AND CHEMICAL ANALYSES OF RIGID EXPLOSIVE TRANSFER LINES ON AH-1S AIRCRAFT

[4.7 years service]

Test group	Manufacture date	Test date	Average functional performance results (standard deviation as percent of average)					Average chemical analysis results		
			No. test firings	Velocity, ft/sec			Energy, in-lb	No. tested	Percent total explosive by weight	
				Line	Axial fragment	Side fragment			HNS-II/HNBiB in transfer line	HNS-I/HNBiB in booster tip
Performance standard (no service)	7/77 to 12/79	1/81	21	22 737 (0.9)	9 366 (11.4)	8183 (3.6)	511 (12.3)	2	97.0	99.8
Service life demonstration	4/77 to 2/78	6/82	20	22 726 (1.7)	10 511 (10.8)	8778 (4.9)	414 (17.9)	2	98.7	99.4
Repeat thermal qualification:	4/77 to 3/78	7/82								
-110°F for 72 hr			20	22 768 (1.3)	9 898 (14.8)	8614 (11.1)	442 (16.5)	2	99.1	99.8
+200°F for 72 hr			20	22 804 (0.9)	10 459 (7.7)	8985 (4.9)	469 (17.9)	2	96.7	100.9
Degradation investigation:	6/77 to 5/78									
375°F for 50 hr		2/81	12	22 944 (0.5)	9 415 (11.3)	8198 (2.5)	458 (23.4)	2	99.8	98.0
400°F for 50 hr		3/81	13	22 918 (0.9)	9 549 (12.5)	8249 (5.4)	[a]446 (6.0)	4	88.0	94.1

[a]Two propagation failures at mid line.

TABLE II.- FUNCTIONAL AND CHEMICAL ANALYSES OF FLEXIBLE EXPLOSIVE TRANSFER LINES ON B-1A AIRCRAFT

[3 years service, aluminum sheath]

Test group	Manufacture date	Test date	Average functional performance results (standard deviation as percent of average)					Average chemical analysis results		
			No. test firings	Velocity, ft/sec			Energy, in-lb	No. tested	Percent total explosive by weight	
				Line	Axial fragment	Side fragment			HNS-II/HNBiB in transfer line	HNS-I/HNBiB in booster tip
B-1A service life demonstration	7/73 to 8/77	3/83	16	22 414 (1.1)	9780 (14.1)	8292 (4.9)	404.7 (21.4)	4	92.3	98.7
Repeat thermal qualification plus 200 wrap cycles	3/73 to 8/77	6/83	11	22 601 (1.9)	9007 (9.9)	8782 (2.4)	--	3	96.7	97.9

[a]Four units had transfer line cracks.
Two units failed to function.

TABLE III.- FUNCTIONAL AND CHEMICAL ANALYSES OF ONE-WAY TRANSFERS ON B-1A AIRCRAFT

[3 years service]

Test group	Manufacture date	Test date	Average functional performance results (standard deviation as percent of average)			Average chemical analysis results	
			No. test firings	Velocity, ft/sec		No. tested	Percent total explosive by weight
				In body	Output fragments		HNS-I/HNBiB in input
Performance standard (no service)	9/77	9/84	10	13 772 (13.9)	8402 (6.8)	3	98.2
Service life demonstration (aircraft 2)	10/72 to 10/73	5/83	11	13 748 (18.7)	8250 (9.0)	3	99.3
Service life demonstration (aircraft 4)	7/75	9/83	21	14 368 (23.2)	8697 (4.5)	2	98.6
Repeat thermal qualification	7/75	10/83	9	12 762 (17.4)	8876 (3.8)	1	98.6

TABLE IV.- FUNCTIONAL AND CHEMICAL ANALYSES OF FLEXIBLE LINEAR SHAPED CHARGE ON B-1A AIRCRAFT

[3 years service, 20 grains/foot, aluminum sheath]

Test group	Manufacture date	Test date	Average functional performance results (standard deviation as percent of average)			Average chemical analysis results		
			No. test firings	Velocity of propagation ft/sec	Cut inch	No. tested	Percent total explosive by weight	
							HNS-II/HNBiB in FLSC	HNS/HNBiB in booster tip
Performance standard (no service)	4/78	7/83	10	23 101 (.4)	.146 (5.1)	2	100.7	99.2
Service life demonstration	6/73	8/83	10	22 942 (.4)	.146 (6.8)	8	98.8	99.6
Repeat thermal qualification	6/73	10/83	22	22 774 (2.0)	.141 (7.1)	2	100.9	99.6
Degradation investigation	6/73							
400°F for 50 hr.		8/83	2	22 575	.149	1	98.8	96.3
425°F for 50 hr.		9/83	2	22 481	.149	1	99.5	99.1
450°F for 50 hr.		10/83	2	22 236	.135	1	99.8	99.8

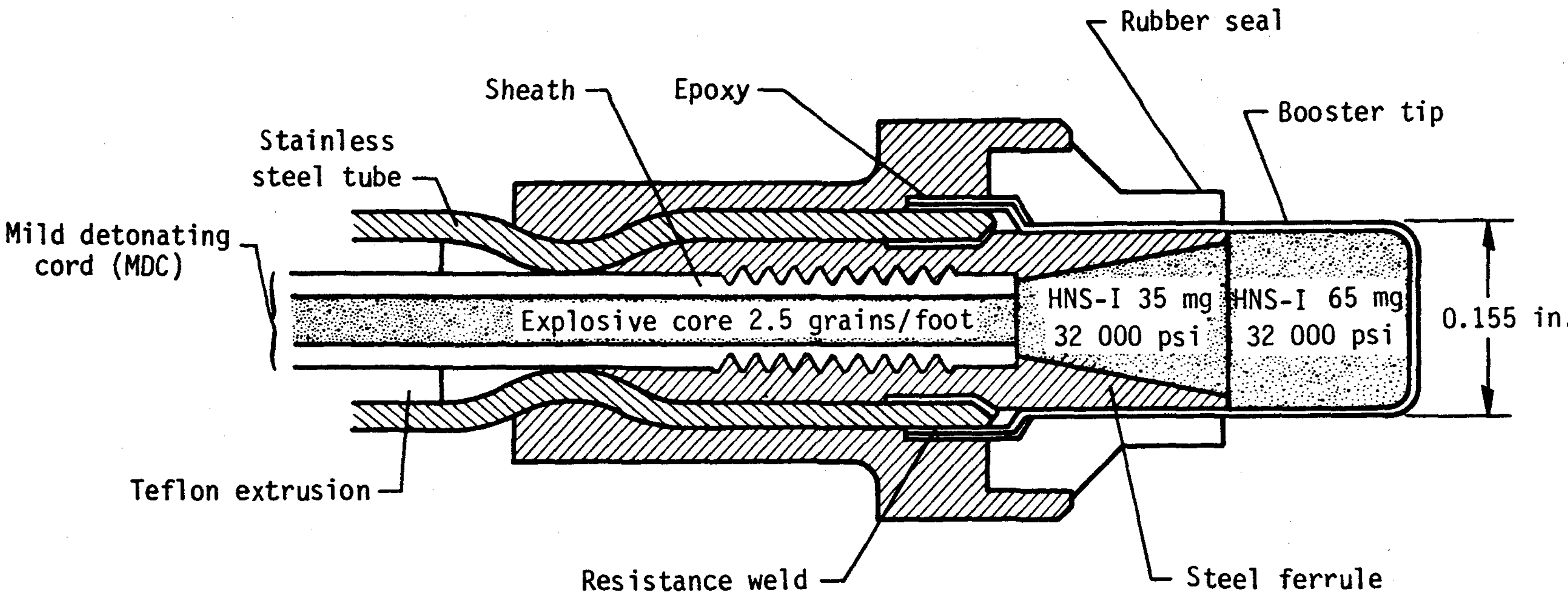

Figure 1.- Cross section of rigid explosive transfer line (1 grain = 65 mg).

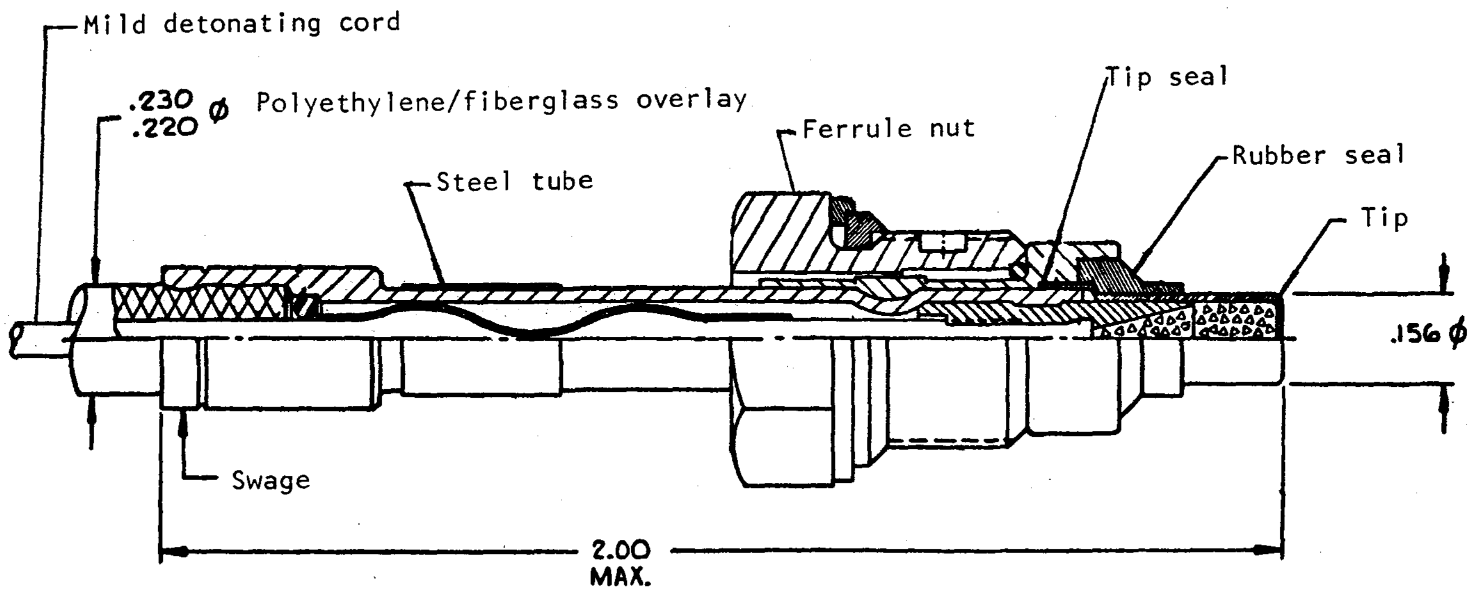

Figure 2.- Cross section of B-1 flexible explosive transfer line.

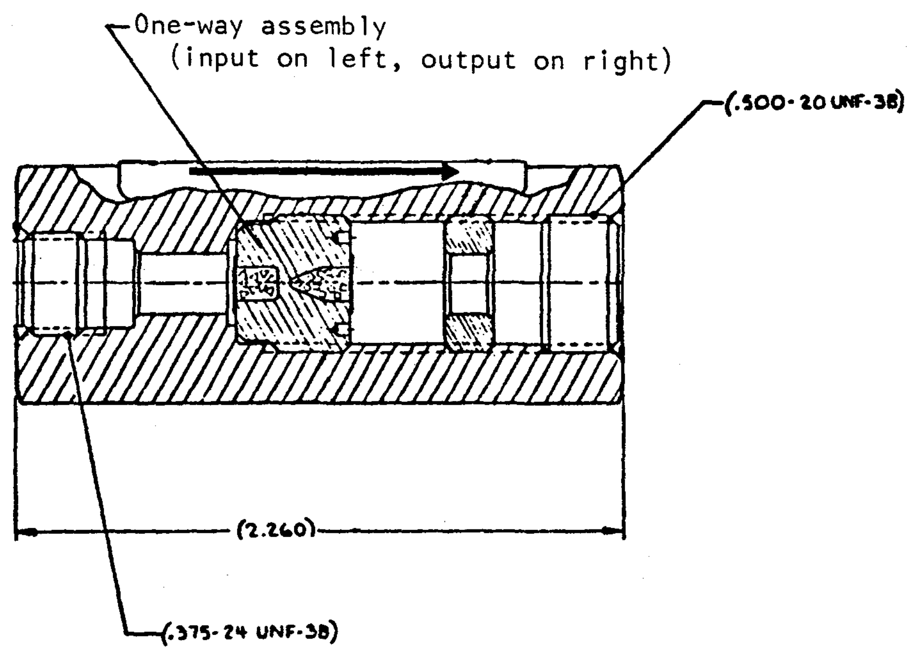

Figure 3.- Cross section of B-1 one-way transfers.

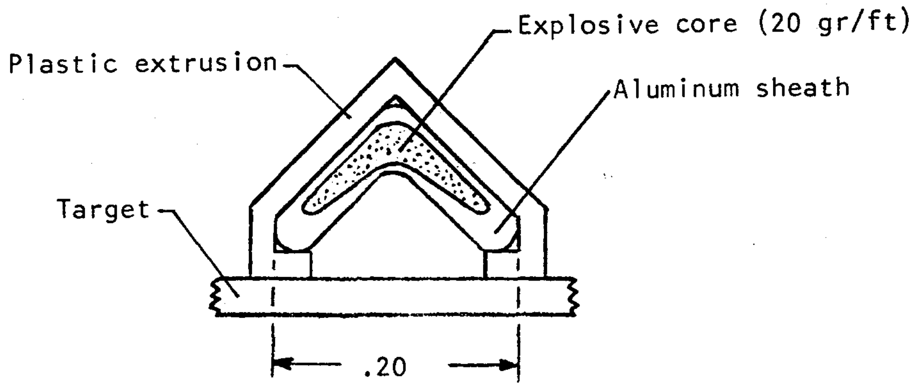

Figure 4.- Cross section of B-1 flexible linear shaped charge.

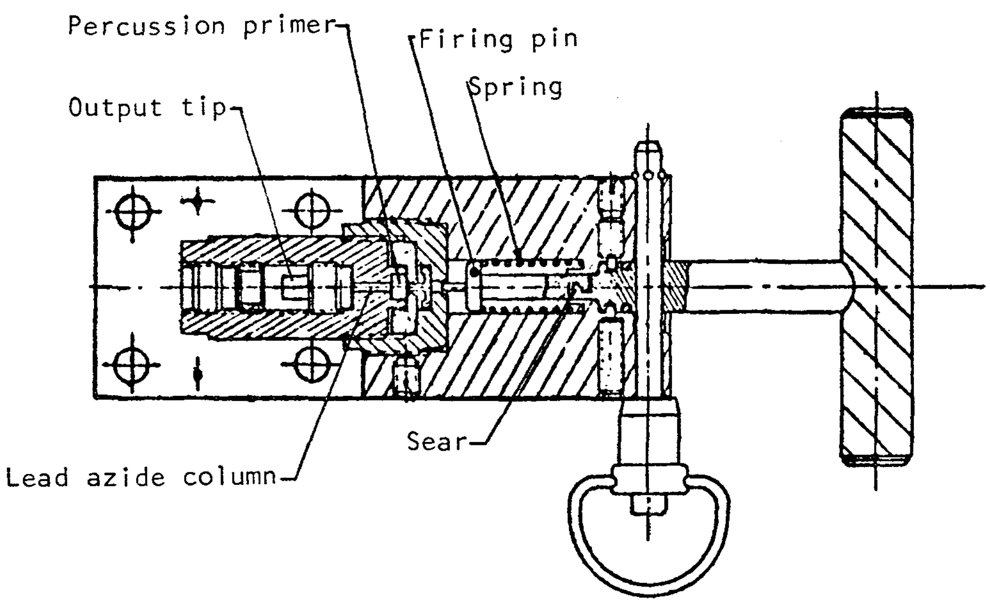

Figure 5.- Cross section of AH-1G arming/firing mechanism.

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15. Supplementary Notes

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16. Abstract

This paper describes a joint Army/NASA/Air Force-sponsored research program on the service life evaluation of explosive devices used in a wide variety of aircraft escape systems. The purpose of this program was to develop a service-extension approach, supported by tests on candidate devices, to evaluate the effects of service, age, and degradation, and allow responsible, conservative, service life determinations. An overview is given on the recommended approach and experimental procedures for accurate service evaluations with test results on rigid and flexible explosive transfer lines, one-way transfers, and flexible linear shaped charges.

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